Land Use Policy 81 (2019) 185–193

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Assessing protected area effectiveness within the Caribbean under changing climate conditions: A case study of the small island, Trinidad

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ARTICLE INFO

Keywords:
Small island
climate change
protected areas
biodiversity
environmental niche modelling
Caribbean

ABSTRACT

Habitat loss and more recently, climate change are primary challenges to the effectiveness of protected area networks (PANs) in species conservation within many archipelagic biodiversity hotspots across the globe. An environmental niche model (ENM) of 11 high-conservation-value tree species was used to assess the effectiveness of the PAN within the Caribbean island of Trinidad under future (2050s) climate conditions. Overlay analyses were conducted inside and outside of existing PANs to determine the proportions of natural and plantation (monoculture) forests. Proportions of this species group's climate space projected to be critical for conservation (combination of stable and expanding zones or 'Z4') that are under forest cover were also calculated. Approximately 63% of Trinidad is forested, with the majority of plantation forests located within the PAN, producing noticeable areas of cleared forest when harvested. The ENM projected a drastic reduction in climate space for this group of high-conservation-value tree species across the island. However, approximately 54% of the Z4 space was projected to occur within the PAN; and 61% of the Z4 falling outside the PAN was under forest cover. Consequently, conservation of this species group could be greatly *enhanced* by increasing the proportion of its Z4 climate space outside the PAN under maintained forest/secondary vegetation cover. Given the small size of small island states (SIS) (such as those in the Caribbean) relative to the macro-scale of climate change, a more effective means of managing climate-induced species loss could involve the development of regional-scale PANs rather than separate efforts of individual SIS.

1. Introduction

Small islands across the world are well known, valuable stores of global biodiversity and endemicity, and human pressure within many of these islands has long been established as a continuing threat to such biota (e.g. Triantis et al. 2010). This ongoing 'biodiversity crisis' requires attention (e.g. Whittaker and Fernández-Palacios 2007) and is now further exacerbated by the impacts of changing climate conditions. The large-scale impacts of climate change upon the limited resources and shrinking natural habitats of these islands may impinge on species' abilities to maintain critical population sizes and genetic variability (Harter et al. 2015).

One region where such conditions are converging is the Caribbean archipelago, one of the world's 'hottest' biodiversity hotspots and a global priority for conservation (Brooks et al. 2006; Maunder et al. 2008; Myers et al. 2000). Despite occupying just over 0.15% of the earth's terrestrial surface, this region contains approximately 7,000 endemic vascular plant species (c. 2.3% of all vascular plants globally) within its remaining vegetation (Mittermeier et al. 2005; Myers et al. 2000).

Until the first decade of the twenty-first century, drivers such as development and agriculture, led to consistently high rates of

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https://doi.org/10.1016/j.landusepol.2018.09.030
Received 4 February 2018; Received in revised form 23 September 2018; Accepted 24 September 2018
Available online 05 November 2018
0264-8377/

deforestation across the Caribbean. Forest fragmentation and removal rates within Caribbean Small Island States (SIS) were continuously ranked amongst the highest in the tropics (Rudel 2005; Tole 2002), leading to the prediction that this region could suffer the greatest loss of endemic species globally (Brooks et al. 2002).

Reduced rates of deforestation and increased forest patch size were later reported for some islands including Puerto Rico, Grenada, Barbados and Jamaica (e.g. Helmer et al. 2008). Exogenous drivers, such as reduced large-scale sugar-cane production due to competition from highly-mechanised, Brazilian and North American sugar cane production, and the removal of quotas and subsidies by the European Union led to the deforestation trend being halted, and somewhat reversed, in several SIS (McDonald 2004).

However, competition arising from land scarcity, for high-priority anthropogenic needs has prevented this forest regrowth to continue unabated. In countries such as Trinidad and Tobago (Maharaj 2011) and Puerto Rico (Munroe et al. 2005), forest regrowth has been replaced by irreversible forms of development, such as suburbanisation and the spread of industry, housing and commercial activities away from urban centres.

Beyond deforestation, there is the question of how climate change may influence biodiversity within these SIS. Changing climate conditions are already impacting biodiversity within continental regions, including extinctions and shifting species' geographic ranges across taxonomic and functional groups (e.g. Hickling et al. 2006; Lenoir et al. 2008; Pounds et al. 2006). While there have been very few similar studies conducted within the Caribbean SIS (e.g. Maharaj and New 2013; Spiers et al. 2018), the small, limited terrestrial spaces with accompanying steep climate gradients of many Caribbean SIS imply that species may have little opportunity to shift their geographical ranges in response to changing conditions.

Losses in biodiversity could serve to further undermine the adaptive capacity of these island ecosystems and thereby increase their vulnerabilities to natural disasters and environmental stress. Hence, dependence upon protected areas (PAs), which have traditionally been key conservation instruments may be critical towards continued planning and management of species within SIS.

On a global basis, PAs such as forest reserves and national parks, have been remarkably successful in the conservation of species, ecosystems and natural landscape features, especially with respect to historical drivers such as fragmentation and habitat degradation. Over the past decades, PA design and management have increased in sophistication and are now created towards ecosystem management focusing upon promotion and sustenance of spatial and temporal heterogeneity in order to promote variability and resilience (Naro-Maciel et al. 2008).

Further, within small island systems, the ecosystem services provided by forests within PAs are also critical for maintaining resilience and buffering against a slew of changes that are already resulting from changing climate conditions such as increasing frequencies of drought, increasingly intense hurricanes, erosion and storm surges. Additionally, such forests are known to contribute to the national economies of some SIS by the provision of food, fuelwood, ecotourism and other non-timber forest products (Mimura et al. 2007).

However, most Caribbean forest reserves were established during the early twentieth century primarily for managing production of a limited range of economically-valuable tree species rather than for conservation (Kenny 2000). By the late twentieth century some of these forest reserves were reoriented towards conservation. But governmental support for PA infrastructure is limited because long-term funding commitments are necessary and there are many conflicting land uses (Leach 2008). Furthermore, funding for the biodiversity surveys that are essential for PA establishment and demarcation has mostly come from international agencies (Leach 2008).

In recent decades, there has however been an increase in the number of PAs within the Caribbean, including the establishment of Natural Heritage sites, and the increased involvement of influential Non-Governmental Organisations. This includes the designation of remnant forest fragments as reserves by many governments in an effort to halt the decline in tropical forests (Naughton-Treves et al. 2005). Perhaps as a means of avoiding political conflict (Cropper et al. 2001), this designation has resulted in the establishment of a negative correlation between urbanisation/agriculture and elevation/topographic complexity/inaccessibility (Helmer et al. 2008; Parés-Ramos et al. 2008).

Further, because many of these PAs were designed without any formal buffer zones (Cropper et al. 2001), their boundaries have become de facto buffer zones, leading to increased risk of encroachment in areas prone to high pressures from exogenous factors such as agriculture, industry and urbanisation. There have also been multiple incidences of (mainly opportunistic) deforestation *within* PAs which continue unregulated due to the lack of enforcement of the laws prohibiting deforestation within PAs (e.g. Evelyn and Camirand 2003). Moreover, while evidence suggests that the enforcement of such laws can be effective in stemming deforestation within PA boundaries (Gaveau et al. 2009), legislative, political and socio-economic initiatives are required.

Despite these caveats, PAs remain the main avenue for habitat conservation, with very little other incentivised options available across the Caribbean as a whole. For example, while a select few of the larger Caribbean SIS such as Jamaica, the Dominican Republic, Cuba and Puerto Rico are now included as partner countries within the UN-REDD or UN-REDD + schemes, none of the smaller Caribbean SIS (e.g. Lesser Antilles) are beneficiaries of such programmes.

It is also noteworthy that while PA networks across the globe have been historically successful at buffering species from drivers such as habitat destruction and encroachment, they are location focused and based on the 'paradigm of place'. These fixed, limited areas with inflexible political boundaries will likely be inadequate the face of species response towards climate change, and the consequences of isolation brought about through habitat destruction (Monzón et al. 2011). On a continental scale, some PAs have already been assessed as unsuitable for supporting future conservation targets (Hannah 2010; Pressey et al. 2007); and other research has demonstrated that the overall expected reduction of species range in response to changing climate will contribute to a net loss of species representation within PA networks (Hannah et al. 2007; Monzón et al. 2011). Some authors have long argued that more research is now required towards planning and development mechanisms for PA networks in order to cope with these already occurring changes (Hannah et al. 2002; Scott and Lemieux 2005). Such work is urgently required within SIS globally, especially because of the extremely limited space available for PA expansion or allocation.

The development of any such planning or adaptation strategies towards protecting species and ecosystems from impacts of climate change and increasing natural habitat fragmentation requires the forecasting of species response to changing conditions. Such forecasting can be done by the application of Environmental Niche Models (ENMs) and can offer critical insights into the present and future effectiveness of PAs (Franklin 2009; Pearson and Dawson 2003). ENMs are correlative and function by first analysing and identifying environmental factors that influence a species' current distribution. These factors are then used to define suitable areas for that species' survival under future climate conditions.

A PA is generally considered to be an effective conservation tool in adaptation response to climate change if it (alone or together with other areas) is able to capture projected climate driven shifts of targeted species (Hannah 2008; Hannah et al. 2007). Several continental and sub-continental examples of PAs have been projected to augment substantially the conservation of species into the future (e.g. Alagador et al. 2011; Araújo et al. 2011) by: (i) the incorporation of climate change into conservation planning strategies; and (ii) the creation of new PAs, which in conjunction with current PAs meet biodiversity targets

simultaneously for present and future climate conditions.

However, such research has not been done for the small geographic spaces of SIS such as those within the Caribbean. Furthermore, creation of new PAs is generally not an option for SIS where limited land space and competing anthropogenic needs make it almost impossible to allocate substantial areas of land for conservation efforts.

The present investigation explores as a case study: the future PA effectiveness within the Caribbean island of Trinidad based on the ENM results for a group of 11 High Conservation Value (HCV) tree species previously reported in Maharaj and New (2013). First, natural and plantation forests were mapped across both island and PA scales to understand and quantify forest distribution patterns within protected and non-protected areas. Given the knowledge that PAs are experiencing forest loss, we further determined and quantified major sources of such loss within our study area. Then by applying the ENM results, the impact of PA placement and deforestation within them on the effectiveness of PAs for future conservation of HCV species was investigated. By focusing on Trinidad, possible adaptation suggestions for species conservation at both the individual SIS and regional scales, when official expansion of individual PAs is not an option, could be made.

2. Materials and Methods

2.1. Study Area

Separated from Northern Venezuela approximately 11 000 years ago (Joseph 1970), Trinidad is the southernmost island of the Caribbean (between 10° 38′ N and 61° 23′ W) (Algar and Pindell 1993). Its flora remains predominantly a relic of the delta from which it separated 11 000 years ago but also contains some endemics that have evolved since this separation, as well as a large number of exotics introduced by human colonisation (Kenny 2000; Santiago-Valentin and Olmstead 2004).

Its PAs, are faced with many challenges mentioned above. Foremost among these are the lack of recognised buffer zones and a severe lack of enforcement preventing deforestation due to both legal and illegal quarrying and logging, squatting for settlement and shifting agriculture (Kenny 2000).

It is however, the only island within the Caribbean with a detailed location database of its vegetation, a critical requirement for ENM (Baksh-Comeau et al. 2016). This database provides a good example of the ubiquitous nature of many vegetation species spread across the Lesser and Greater Antilles, northern South America and southern North America (Baksh-Comeau et al. 2016) - demonstrating that the climate envelopes of many species are not limited to the current political boundaries of individual islands (Table 1).

2.2. Generation of a forest-cover map

A forest-cover analysis of Trinidad was conducted using Landsat 8 satellite imagery. Cloud masks were created using the Quality Assessment Band (Band 9) and cloud shadow areas were identified by performing an Iso Cluster analysis on Band 5 (near infrared band) in ArcGIS 10.3. A combination of scenes was selected (ranging from September 2013 to January 2015) to create a gap-filled image of Trinidad which yielded spectral data for 90% of the island's area. Landsat 8 surface reflectance products were then used to create a composite image (Bands 2 to 7) for Trinidad. Training sites were identified visually based upon the 2007 Ikonos satellite imagery, local knowledge and site visits. Our training classes included: forest, mangrove, active agricultural fields, abandoned agriculture fields, brush/scrub, urban areas, quarried areas, burnt areas, bare earth, coconut plantation, bamboo and coconut forest.

We used the ArcGIS 10.3 Image Classification tools to conduct a Maximum Likelihood supervised classification, and classification areas of missing data were manually in-filled using the 2007 Ikonos satellite imagery. The quality of the classification was then assessed using a confusion (error) matrix: which assesses the accuracy of the classified image by comparing a selection of points from the output classified landcover product to the ground-truth landcover from a reference image. Our reference image consisted of aerial photography collected for Trinidad in 2014 and 2015.

A stratified random sample based upon the spatial extent of each predicted landcover (with a minimum of 30 ground truthing points per landcover class) was then conducted for a total of 357 points distributed throughout the island. This yielded an overall accuracy of 89.64%, a Kappa value of 0.87, (comparison of the classification result to values assigned by random chance). The accuracy of the forest class identification yielded producer's and consumer's accuracy values of 97% and 87.40% respectively. From this classification, a map illustrating forest cover over Trinidad between 2013–2015 (Fig. 1) was created with all non-forest classes being agglomerated to 'Non-Forest', including coconut forest as this is considered to be in an early stage of succession, hence lacking the ecological functioning of forests.

2.3. ENM results of HCV species defined by Maharaj and New (2013)

Environmental niche models of 11 HCV tree species (based on ecological importance, global/regional rarity and commercial importance) across Trinidad were built by Maharaj and New (2013) using

Table 1
Geographical distribution range for HCV species modelled.

Species	Geographical Distribution Range
Brosimum alicastrum	Greater Antilles (Cuba, Jamaica, Puerto Rico), Lesser Antilles (St. Vincent, the Grenadines – Carriacou), United States (Florida), Mexico (Campeche, Chiapas, Quintana Roo, Tabasco, Veracruz, Yucatan), Central America (Belize to Costa Rica, [Panama]), Colombia, Venezuela, the Guianas, Brazil, Ecuador, Peru, Bolivia, Hawaii
Calophyllum lucidum	Guyana, French Guiana
Carapa guianensis	Greater Antilles (Cuba, Hispaniola), Lesser Antilles (Guadeloupe, Marie Galante, Dominica, Martinique, St. Lucia, St. Vincent, Grenada), Central America (Belize to Honduras, Nicaragua to Panama), Colombia, Venezuela, the Guianas, Brazil, Ecuador, Peru
Eugenia confusa	Bahamas, Greater Antilles (Cuba, Hispaniola, Jamaica, Puerto Rico), Virgin Islands (St. John), Lesser Antilles (Antigua to St. Lucia), United States (Florida)
Ilex arimensis	Endemic to Trinidad and Tobago
Mora excelsa	Venezuela, Guyana, Surinam, Brazil
Sterculia puriens var. *glabrescens*	Lesser Antilles (St. Vincent), Venezuela, western Guyana, Ecuador
Tabebuia stenocalyx	Venezuela, Guyana, French Guiana, Brazil
Tabernaemontana attenuata	Venezuela, Surinam, French Guiana
Tovomita eggersii	Venezuela, Guyana
Virola surinamensis	Lesser Antilles (Martinique), Central America (Costa Rica, Panama), Colombia, Venezuela, the Guianas, Brazil, Ecuador, Peru, Bolivia

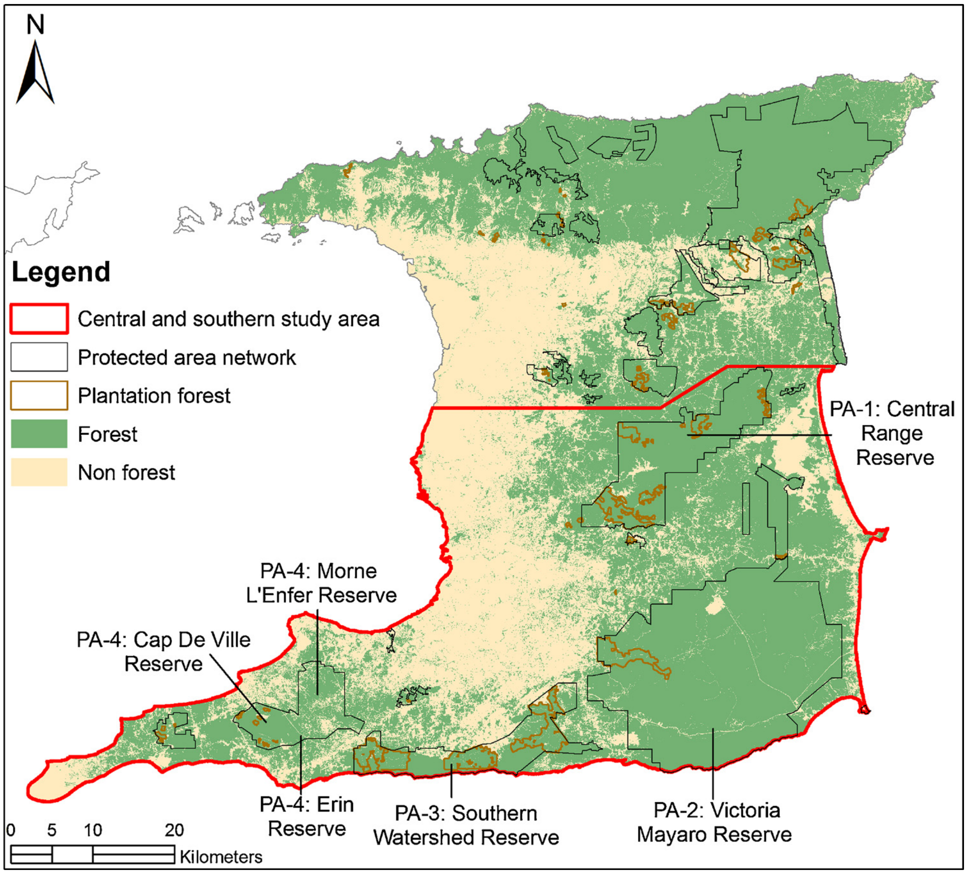

Fig. 1. Forest cover map for Trinidad during 2013 to 2015 period: Distribution of Natural Forest, Plantation Forest and Non-Forest across Trinidad.

the MaxEnt species distribution algorithm and climate data from both present and future (2050; SRES A2) time periods (Table 1). This Special Report on Emissions Scenarios (SRES) A2 scenario describes conditions that are intermediate between the newer suite of Representative Concentration Pathways (RCP) 6.0 (a mild climate-policy intervention scenario) and 8.5 ('business as usual' scenario) during the 2050s (Cubasch et al. 2013).

The environmental variables found contribute most to the distribution of these species were mainly precipitation-based and include: precipitation of the driest 3-month period, precipitation of the wettest month, precipitation of the driest month and elevation.

The authors incorporated the ENMs of these 11 species to develop a collective change map illustrating the projected expansion, contraction and areas of stable environmental space for this group of 11 species from the present to 2050 under SRES A2 conditions (Fig. 2a). This collective change map indicates that this species group's suitable environmental space is projected to decrease to less than half its present range, with areas of stable and expanding range projected to occur mainly along the central and western regions of Trinidad's southern edge, tapering towards the centre of the island.

2.4. Definition of study area

Our analyses were ultimately based upon the collective change map's combination of stable + expanding zones: hereafter referred to as zone 4 ('Z4') (Fig. 2b). Z4 illustrates regions projected to be critical for conservation planning as it represents suitable areas for growth and survival during both the present and future conditions. Additionally, the prevailing premise underlying the use of ENMs for forecasting suggests that because of uncertainties in climate data and scale, interpretation of ENM model output should be limited to *general* spatial patterns and not finer details (Franklin 2009). Hence, we limited our study area to the four major PAs (PA1 to PA4) in the central and southern regions of the island and excluded the limited representation of Z4 within the substantially larger PAs to the north (Fig. 2b).

2.5. Overlay analysis and other forest cover calculations

From Fig. 1, the proportions of natural forest, plantation forest and non-forested areas were calculated within ArcGIS 10.0, for the following extents:

(i) the entire island
(ii) within the study area:

a inside the PAN,
b outside the PAN
c a 100 m buffer zone external to the PAN (Table 2)

From Fig. 2, we then calculated the proportions inside vs outside of the study area's PAN projected for species group's climate space zones of:

(i) expansion (Z1)
(ii) contraction (Z2)
(iii) stable (Z3)
(iv) expansion + stable (Z4) (Fig. 3a)

Figs. 1 and 2 were also used to calculate occupied vs unoccupied proportions of the Z1 to Z4 - for both inside and outside of the PAN (Fig. 3b). Where: (i) 'Occupied' = areas within Z1 to Z4 that were under forest cover (including plantation forests); and (ii) 'Unoccupied' = areas within Z1 to Z4 that were NOT under forest cover (e.g. anthropogenic activities: agriculture, settlement and industry).

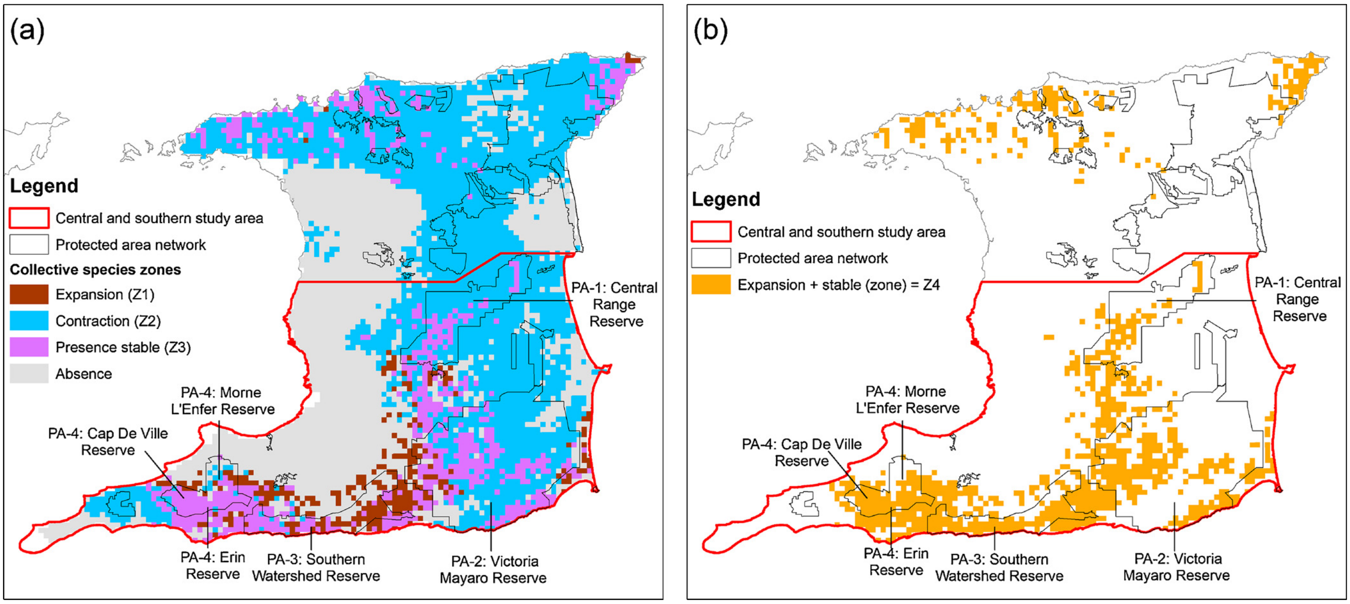

Fig. 2. Collective Species Model for group of selected High Conservation Species from present climate conditions to the period 2035-2065 (SRES A2 scenario). (2a): Projected zones of group expansion (Z1), contraction (Z2) and stability (Z3) and (2b): Zone critical for group conservation (Z4) = (Z1 + Z3).

3. Results

3.1. Forest cover across Trinidad

Approximately 63.3% of Trinidad is under forest cover, which is concentrated along both the northern and southern edges as well as the east-central region of the island (Fig. 1). Forest cover was highly fragmented within the central, south-central and south-western parts of the island, particularly, but not exclusively, outside of the PAN. Additionally, while the majority of the PAN was covered with contiguous expanses of forest, there were areas inside the PAN, particularly within PAs to the south of the island, that appear to have been cleared of forest. Finally, plantation forests were found to be located within the PAN, particularly within the central and southern PAs.

3.2. Plantation versus Natural forest cover

Little more than half of the total forest within the study area is located outside the PAN (Table 2). However, the vast majority of plantation forests are located within 10% of the PAN, with very few areas of such forest being established elsewhere on the island. Furthermore, approximately one third of the plantation forests occurring outside the PAN are found within 100 m of the PAN boundaries.

3.3. Environmental niche model of species group

Fig. 2a reveals an approximately 78% reduction in the projected future environmental niche of this group of HCV species at the island scale, with about 81% of areas projected to be viable conservation planning for these species (Z4) being limited to the southern and central regions (Fig. 2b). Overlay analysis between the study area's PAN and the collective model in Fig. 2a revealed that this group's projected stable zone (Z3) appeared to be distributed inside and along the peripheries of PAs 1-4. However, most of its projected expansion zone (Z1) was observed to occur inside or along the external periphery of PA-3 and to a lesser extent, along the edges of PA-2 and PA-4.

Proportions of Z1 to Z4 within the study area's PAN varied, with over half of both the zone of expansion (66%) and the zone of contraction (58%) situated outside of the PAN, together with approximately 37% of the stable zone. However, almost 54% of the area critical for conservation planning for this group of species (Z4) was located inside the PAN (Fig. 3a).

Overlaying of the forest cover (Fig. 1) with the collective change map (Fig. 2) revealed that within the study area, over 90% of all collective species zones (Z1 to Z4) inside of the PAN were covered by forest (Fig. 3b). The proportion of forest cover within these zones to the exterior of the PAN was noticeably less, ranging from approximately 55% in Z1 (collective expansion zone) to 75% in Z3 (collective stable zone). Also noteworthy is that approximately 61% of Z4 outside the PAN was covered with forest.

4. Discussion

The small size of the average SIS, relative to the macro-scale of

Table 2
Proportions of Trinidad's natural and plantation forests at the (i) island and (ii) study area's PAN (internal & external) and buffer scales.

	Extent	Spatial Area of Extent (ha)	Forest within Extent (ha)	Forest Type (%)	Spatial Area of Plantation forest (ha)
	Island	481,428	304,467	Plantation forest 3.5 Natural forest 96.5	~10, 656
Study area	Inside PAN	89,992.2	84,707.6	Plantation forest 10.0 Natural forest 90.0	~8470
	Outside PAN	193,599	90,481.1	Plantation forest 0.4 Natural forest 99.6	~362
	100 m buffer exterior to PAN	3,580.6	2,534.8	Plantation forest 4.0 Natural forest 96.0	~101

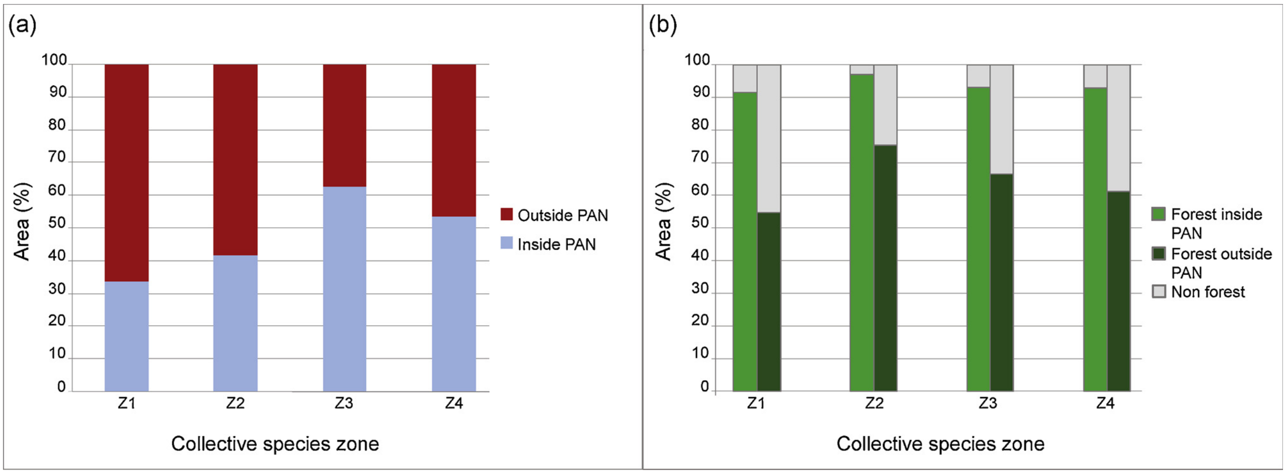

Fig. 3. Distribution of species group's environmental space inside and outside PAN and with respect to forest cover. (3a): Proportion of species group's zones inside and outside the study area's PAN and (3b): proportion of species group's zones inside and outside study area's PAN under forest cover.

climate change, implies that sole dependence on PAs within individual islands will be an ineffective means of species conservation into the future. Additionally, the distances separating individual PAs within these islands are likely to be small, and the land use within such non-protected separating spaces may be critical in aiding the future species' survival. Within the Caribbean SIS, ongoing competition for such unprotected land, due to the limited size of these islands, complicates land use management, and adds to the urgency of developing sustainable solutions to the problem.

Collective species ENMs (e.g. Fig. 2) can be useful tools for assessing the potential effectiveness of PAs by illustrating areas that are likely to be suitable for species survival during both present and future climates. The information they provide on potential changes in species range can offer valuable direction in climate adaptation, proofing and resilience endeavours. For example, guidance on areas that are more suitable for human use versus where should not be cleared of natural vegetation: to facilitate longer-term adaptation such as the maintenance of water storage capacity or development of seedbanks for the preservation of important species.

The small size of such islands also increases the likelihood that existing PAs may not be appropriately placed to support future environmental niches of species projected to contract or shift under future climate conditions. This was the case for Trinidad where the larger, more extensive and mountainous (hence more protected from human activity and clearing) PAs to the north of the island were projected to be unsuitable for the future survival of the group of species investigated (Fig. 2). In contrast, the PAs to the south and central regions are projected to facilitate future survival of these species but they are readily accessible, and hence susceptible to anthropogenic encroachment.

GIS analysis of forest cover change across Trinidad between 1969 and 2007 showed an overall increasing rate of deforestation both inside and outside the PAN (Maharaj 2011). It also reported an eastward migration of a 'band of deforestation' towards the PAN from areas of high anthropogenic development within the western part of the island. Perhaps symptomatic of this progressive encroachment, the current GIS analyses showed many portions of the PAN boundary directly exposed to deforestation without the presence of a forested buffer (Fig. 1). This analysis also indicated that while there was less forest fragmentation inside versus outside the PAN, the effectiveness of the PAN in preserving forest cover could be compromised, with approximately 6% of the PAN being without any type of forest cover. Furthermore, a large portion of this non-forested area consists of previously harvested plantation (monoculture) forests that have been clear-felled.

With the vast majority of plantation forests within the entire island being located within our study area's PAN and its 100 m external buffer (Table 2), there is an urgent need for dialogue with the Forestry Division of Trinidad and Tobago which owns and manages most of the timber monocultures across the island. These plantations of teak (*Tectona grandis*) and pine (*Pinus caribaea*) are periodically clear-felled, leaving large areas of land exposed and un-vegetated. Additionally, both teak and pine monocultures are well known for their soil damaging qualities, making the future establishment of native tree species extremely difficult (e.g. Harikrishnan et al. 2012; Nissanka et al. 2005).

Despite plantation forests within PAs, the PAs of the study area provide protection in areas critical for the future survival of the study species, with 54% of Z4 being located within the PAN (Fig. 3a) and over 90% of this proportion being under forest cover (Fig. 3b). However, with approximately 67% of the area projected to facilitate future expansion of this group of species (Z1) and almost half of the stable zone and Z4 located outside of the PAN, the collective future survival of this group could be greatly enhanced by stabilizing and eventually increasing the proportion of the Z4 external to the PAN under maintained forest cover or at least a secondary vegetation matrix. A baseline for such a strategy already exists as 61% of the Z4 located outside the PAN is presently under forest cover (Fig. 3b).

However, strategies geared towards expansion and maintenance of forest cover outside these PAs are not straightforward and will vary depending on the distribution of Z4. In this case, a seemingly practicable option to stabilize and eventually increase forest cover of the Z4 outside of the PAN would be to: (a) merge PA-2, PA-3 and PA-4; and (b) expand these PAs to encompass their external peripheries (which are especially important for future expansion of this group of species). However, while PA-3 and PA-4 fall almost completely within Z4, satellite imagery indicates that forest within PA-4 has been replaced by irreversible forms of development such as settlement and industry. Additionally, portions of PA-3 have been converted to teak and pine plantations by the local Forestry Division. Further, of the almost half of the Z4 projected to lie at the external peripheries of these PAs, its largest contiguous portion lies between the PA-3 and PA-2. However, these areas are privately owned and apart from continued deforestation, may be difficult to acquire due to widespread squatting and shifting agriculture.

4.1. Maintenance of forests outside of PAN

There are however, adaptation strategies such as those suggested for other threatened larger-island systems, such as the Galapagos and the United Kingdom, which may aid in situations such as this within SIS. Such strategies are oriented towards conservation of high-quality, non-protected habitat and the minimization of habitat fragmentation. This

involves the maintenance of existing PAs in conjunction with the creation of: (i) new ecological networks; (ii) buffer zones around forests and other high-quality habitat; and (iii) more resilient agricultural landscapes such as agroforestry (Smithers et al. 2008). These ideas may be possible with the collaboration of science, and political will together with the co-operation of land owners and other stakeholders with holdings bordering the peripheries of these PAs.

Further, with legislation already supporting Trinidad and Tobago's National Protected Areas and National Forest policies (2009a,b) towards the 'maintenance of forest ecosystems in light of competing demands for land' there is potential to facilitate the minimization (and subsequent active restoration) of teak and pine cultivations within these southern PAs by the local Forestry Division. Such restoration could involve the substitution of teak and pine with mixtures of native species, especially those which may have both high timber value (future income with the use of selective-felling harvesting methods), and can also provide resources for wildlife (Lamb et al. 2005; Montagnini 2001). Such extractive reserves and others which combine conservation and development goals, initially suggested by The Rubber Tapper's Council in Brazil are quite well known (Ruiz Perez et al. 2005). Indeed, there are examples of reserves being managed not only by government, but also via cooperative arrangements, communities and private stakeholders (Naro-Maciel et al. 2008).

Additionally, potential for the maintenance and establishment (and increasing connectivity) of secondary forest outside of the PAN, has been demonstrated in other cases by the enlistment of co-operation from private land owners via introduction of tax breaks and community incentives such as 'Payments for Ecosystem Services' (PES) (Jack et al. 2008; Tacconi 2012). Similarly, encouragement of the replacement of row-crop and other intensive forms of agriculture within these areas with agroforestry such as fruit trees, cocoa and coffee plantations may help to quell deforestation and promote creation of secondary forest around these PAs. Apart from providing natural harbours to both wildlife and agricultural biodiversity (Peters et al. 2016; Wilson and Lovell 2016), these plantations can also be designed to incorporate fire management strategies such as fire breaks, which are invaluable mechanisms in reducing the threat of forest fires (often maliciously set by shifting agriculturalists) within and around the PAN (Myers, 2006).

Furthermore, the implementation of policies directed towards small holdings of agricultural lands (usually row-crop mono-cultures) which disseminate agro-ecological knowledge and the diversifying of these landscapes have been demonstrated as an effective means of promoting a matrix of semi-natural areas (Kovács-Hostyánszki et al. 2017). Such initiatives can be supported by economic instruments such as PES. Several successful examples of such schemes which pay landowners to protect remaining forest within their holdings and integrate trees into their farming systems have been reported in Central America (e.g. Pagiola et al. 2005). It is noteworthy that the active involvement of local communities in the management of forests and other natural areas have been shown to be equally or even more effective in maintaining forest cover compared to schemes based solely on exclusion (Ellis and Porter-Bolland 2008; Porter-Bolland et al. 2012). However, successful maintenance of such initiatives require enforced legislation that promotes the maintenance of secondary forest by the restriction of deforestation and the regulation of logging as well as of the tenure rights of resident squatters (Wallace et al. 2005).

4.2. Regional PAN?

Even if natural areas within these southern PAs and their peripheries are protected, maintained and also expanded, would it be possible to sustain their survival beyond the 40-year projection of these models? Any progression of further anthropogenic encroachment or of climate change beyond the levels used in these analyses may likely result in further reductions or even the disappearance of the climate space of at least some of these species. Indeed, as changing climate conditions are not limited to political boundaries, perhaps a more effective means of managing and to some extent, controlling this species loss within the Caribbean SIS should involve the development of a regional-scale, Caribbean PAN rather than individual SIS separately attempting species conservation within the limited PAN of each island.

As illustrated in Table 1, the distribution ranges for most of the 11 species used in the ENM analyses are not associated with political boundaries. These species presently occur beyond Trinidad, including the Lesser and Greater Antilles as well as varying parts of South and Central America and southern North America. However, unlike Trinidad, most Caribbean SIS have no continental influence and many are well known for their high levels of biodiversity and endemicity (Myers et al. 2000). The use of ENMs to project suitable climate spaces for such valuable species across the entire Caribbean (rather than just one island) may provide much needed space and opportunity for future conservation of these target species.

Such an endeavour would require enormous collaboration and coordination of the Caribbean SIS and neighbouring territories across many levels of planning. Additionally, a 'regional PAN' would require more comprehensive ENM approaches involving the development of model ensembles (Araújo and New 2007) from multiple updated GCMs such as Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs).

Adapting from structures such as the Systematic Conservation Planning (SCP) framework proposed by Margules and Pressey (2000), the development of such a regional conservation programme would have several pre-requisites. These include: (i) agreement and involvement among regional stakeholders such as members of CARICOM and Venezuela; (ii) development of baselines for species presence and distributions within individual SIS, from which a regional database can be developed; (iii) identification of conservation goals for both individual SIS and the Caribbean region as a whole; (iv) review of the existing PAN at both the individual SIS and Caribbean scales; (v) selection of additional conservation areas (including incentivised non-protected areas) where possible; and (vi) implementation of conservation actions.

This could ideally allow for flexible and accountable means of addressing competing land uses and allowing for critical review of decisions (McDonald 2009). While it is unrealistic to expect all parts of this framework to be successfully implemented initially, this SCP does provide an initial guide to the general requirements to be addressed if regional conservation is attempted. Progression beyond this point would require consideration and integration of the unique economic, political and social requirements of the densely-populated SIS which continue to take precedence over the allocation of PAs. Additionally, the revisiting of international conventions addressing the rights of individual countries to unique aspects of their biodiversity (e.g. the Convention on Biological Diversity [CBD]) may be required. Hence political goodwill and cooperation and collaboration among member nations are critical for such work to be attempted. If applied, at least partially, a regional approach would likely not conserve all target species but could at least increase the potential for managing the rate of species loss.

Additionally, such an endeavour requiring regional collaboration and sharing of expertise could produce other benefits such as capacity building and the construction and maintenance of a much-needed regional database of the conservation status of plant species within the Caribbean. Indeed, it has been pointed out that cross-border collaboration efforts can be an effective and less costly means of increasing the efficiency of conservation planning efforts (Kark et al. 2009). Furthermore, this collective approach is likely to increase and bolster the adaptation and resilience capacity at both the island and regional scale in the face of a changing climate.

5. Conclusion

This Caribbean example illustrates the unlikeliness that protected

areas within individual small islands will be solely and adequately capable of preventing species loss with changing climate conditions. With extensions of the PAN within these individual SIS being improbable due to high competing demands for limited space, incentives aimed towards maintaining and increasing forest cover within adjacent unprotected areas may help to augment conservation efforts. However, given the macroscale of climate change relative to the political boundaries of these SIS, the development of a regional (e.g. Caribbean) PAN may be key towards effectively managing or at least controlling species loss within biodiverse island archipelagos across the globe.

Acknowledgements

This work was supported within the framework of the ProEcoServ project at the Department of Life Sciences of the University of the West Indies in Trinidad and Tobago and funded by the Global Environment Facility through the United Nations Environment. We also thank Dr. Nick Brown of Linacre College, University of Oxford for his advice during the initial phases of this research, as well as Dr. Luke Rostant of the University of the West Indies for peripheral comments.

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Glossary

CARICOM: Caribbean community and common market
ENM: Environmental Niche model
HCV: High conservation value
PA: Protected area
PAN: Protected area network
RCPs: Representative concentration pathways
SCP: Systematic conservation planning
SIS: Small island states
SRES: Special report on emissions scenarios
SSPs: Shared socioeconomic pathways